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The Effect of Smoke Inhalation on Lung Function and Airway Responsiveness in Wildland Fire Fighters[1-3]

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SUMMARY The current study was undertaken to evaluate the effect of smoke on forced expiratory volumes and airway responsiveness in wildland fire fighters during a season of active fire fighting. Sixty-three seasonal and full-time wildland fire fighters from five U.S. Department of Agriculture Forest Service (USDAFS) Hotshot crews in Northern California and Montana completed questionnaires, spirometry, and methacholine challenge testing before and after an active season of fire fighting in 1989. There were significant mean individual declines of 0.09, 0.15, and 0.44 L/s in postseason values of FVC, FEV_1, and FEF_{25-75}, respectively, compared with preseason values. There were no consistent significant relationships between mean individual declines of the spirometric parameters and the covariates: sex, smoking history, history of asthma or allergies, years as a fire fighter, upper/lower respiratory symptoms, or membership in a particular Hotshot crew. There was a statistically significant increase in airway responsiveness when comparing preseason methacholine dose-response slopes (DRS) with postseason dose-response slopes ($p = 0.02$). The increase in airway responsiveness appeared to be greatest in fire fighters with a history of lower respiratory symptoms or asthma, but it was not related to smoking history. These data suggest that wildland fire fighting is associated with decreases in lung function and increases in airway responsiveness independent of a history of cigarette smoking. Our findings are consistent with the results of previous studies of municipal fire fighters.
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Introduction

The adverse respiratory health effects of exposure to smoke from fires have been addressed in previous studies. Investigators have documented transient decreases in FVC, FEV_1, and the maximal midexpiratory flow rate (FEF_{25-75}) in crews of municipal fire fighters in association with acute exposure to smoke from a single fire incident (1–4). Transient increases in airway responsiveness as measured by methacholine challenge have also been reported in association with acute exposure to fire smoke (3–6). The long-term effects of fire fighting on lung function are more controversial. Peters and coworkers (7) initially demonstrated a more rapid than expected annual decline in lung function in Boston fire fighters that correlated with the number of fires fought. However, longer-term follow-up of this cohort (8, 9) and the results of at least two other studies (10, 11) failed to confirm this initial finding. On the other hand, Tepper and coworkers (12), in a 6- to 9-yr longitudinal study, have recently demonstrated a 1.7 times greater rate of FEV_1 decline in fire fighters who did not wear respiratory protective equipment than in those who did. Other investigators (13–15) have also postulated that repeated exposure to smoke may contribute to an excess annual decline in lung function among municipal fire fighters compared with that in the normal population.

Fire fighters, both municipal and wildland, are exposed to high levels of smoke. However, the smoke to which they are exposed differs in composition. Municipal fire fighters, also known as structural fire fighters, often are exposed to the pyrolysis products of both natural and synthetic materials (16–19). These compounds include carbon monoxide, hydrogen cyanide, acrolein, oxides of nitrogen, chlorine, and ammonia. Wildland fire fighters are exposed primarily to the combustion products of wood and other natural materials. Pulmonary irritants in wildland fire smoke include aldehydes, acrolein, formaldehyde, ozone, and particulate. A recent study of wildland fire fighters has demonstrated that exposures to aldehydes and particulate may occasionally exceed permissible exposure limits (20). Typically, wildland fire fighters wear only a cotton bandana as a form of respiratory protection.

The current study was undertaken to evaluate the effect of smoke on forced expiratory volumes and airway responsiveness in wildland fire fighters during a season of active fire fighting.

Methods

Subject Selection

The study population consisted of all seasonal and full-time wildland fire fighters from five U.S. Department of Agriculture and Forest Service (USDAFS) Hotshot crews in Northern California and Montana during the 1989 fire season. The USDAFS employs wildland fire fighters on a seasonal (approximately May to November) and full-time basis to respond to wildland fires throughout the country. Crews are organized into groups of approximately 20 men and women who are stationed throughout various regions in the United States. Hotshot crews stay together throughout the fire season. All members of the five Hotshot crews were initially asked to participate in the study (n = 94). The study protocol was approved by the State of California Health and Welfare Agency Committee for the Protection of Human Subjects. Exclusion criteria included refusal to participate and a priori knowledge that a fire fighter would not be available for postseason testing (one subject).

After informed consent, 86 (90%) crew members completed a preseason questionnaire and underwent methacholine (MCh) challenge testing. Sixty-five (69%) crew members returned to complete a postseason questionnaire and MCh testing. Of the 21 fire fighters not available for postseason testing, 19 (90.5%) had returned to their homes before being contacted; one fire fighter transferred to another branch of the fire-fighting

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service, and one fire fighter quit before the end of the season to return to college. No fire fighters were known to have left employment for respiratory or other health problems. Two subjects were given an incorrect starting dose for the MCh test, and they were excluded from analysis. The final study population consisted of 63 fire fighters.

Data Collection

Wildland fire fighters often are difficult to locate during the fire season because they are called to fires on an emergent basis, usually in remote locations that are relatively inaccessible for research purposes. An attempt was made to obtain preshift and postshift spirometry at a base camp during an active fire. However, because of extremely cold weather (21° F), high altitudes, and difficulty in the coordination of testing at the beginning and the end of the shifts, it was not possible to obtain reliable data. Therefore, it was logistically feasible to administer pulmonary function testing, MCh testing, and questionnaires to the Hotshot crew members only at the beginning of the fire season (May) and again at a time after the last fire-fighting activity and before discharge from service (a maximum of 2 wk) in late September and October in 1989.

Standardized self-administered preseason and postseason questionnaires were given to each participant to ascertain demographic information, smoking history, years as a fire fighter, overall occupational history, prior medical history, respiratory symptoms, and other possible sources of exposure to smoke. One of the investigators was available to address queries from the subjects and to check questionnaires for completeness.

Forced expiratory flow rates and FVC were measured on a dry rolling-seal spirometer (S400; Spirotech Division, Anderson Instruments, Inc., Atlanta, GA) in accordance with American Thoracic Society criteria (21). A minimum of three acceptable tracings was recorded, with the subject in the seated position wearing a noseclip; a maximum of eight efforts was allowed. Spirometric tracings were considered reproducible if the two best values for FVC and FEV_1, respectively, were within 5% of each other; the largest FVC and FEV_1 were used for analysis of baseline values. All measurements were corrected for temperature, water saturation, and pressure. Predicted values were those of Knudsen and coworkers (22).

Subjects were instructed not to consume caffeine-containing beverages for 4 h prior to MCh challenge testing. The subjects were interviewed prior to each MCh challenge, and none gave a history of a respiratory tract infection within 2 wk of testing or of using a medication that could affect the results. Only five of the subjects were current smokers, and they were not tested for at least 1 h after smoking a cigarette.

The modified protocol for MCh testing developed by Hendrick and coworkers (23) for epidemiologic studies was used. Phosphate-buffered saline (PBS), followed by as many as 10 doubling concentrations of MCh (0.125, 0.25, 0.5, 1.0, 2.0, 4.0, 8.0, 16.0, 32.0, and 64.0 mg/ml), was administered via a nebulizer (No. 646; DeVilbiss Co., Somerset, PA) with the use of a dosimeter (Model 2A; Laboratory for Applied Immunology, Baltimore, MD) that was calibrated to deliver 8.9 µg of aerosol per inhalation. Three forced expiratory maneuvers in rapid succession were performed to determine FEV_1 exactly 5 min after inhalation of five deep breaths of the PBS and each concentration of MCh. The starting concentration of MCh (0.125, 1.0, or 8.0 mg/ml) was determined individually according to the likelihood of active asthma as assessed by clinical history. The test was terminated when a 20% decrease from the post-PBS FEV_1 occurred or after the maximal concentration of MCh was administered. The overall protocol was designed such that all subjects received the same cumulative dose of MCh by the completion of the test.

Analysis

The degree of airway responsiveness for each subject was determined for his or her MCh dose-response slope (DRS) by the method of O'Connor and coworkers (24). The DRS was selected as the primary measure of airway responsiveness rather than the provocative concentration of MCh that causes a 20% decrease in FEV_1 from baseline FEV_1 (PC_{20}). Because not all subjects may attain a 20% decrease in FEV_1 from baseline FEV_1 before termination of the test, use of PC_{20} would result in censorship of many members of the study population. However, a DRS can be derived for all subjects regardless of the MCh concentration at the termination of the test.

The DRS is defined as the [(post-test FEV_1 − pretest FEV_1)/pretest FEV_1] × 100/cumulative dose of MCh in micromoles. For purposes of DRS calculation, the post-PBS FEV_1 was used as the pretest value. Although it was found that the minimum value for FEV_1 occurred at the first post-MCh forced expiratory effort in 60% of forced expiratory maneuvers for all subjects at each dose of MCh, the mean value of FEV_1 at each dose was used for analysis because other investigators (4, 23) have analyzed MCh test data in this fashion.

Frequency distributions for selected demographic and occupational characteristics were evaluated: age, sex, race, smoking history, history of asthma, and preseason history of upper and lower respiratory tract symptoms. Log transformation of the DRS was performed to normalize the distribution (ln[drs + 1], hereafter referred to as DRS). However, the distribution of the transformed DRS still was highly skewed. Therefore, Wilcoxon's two-sample rank sum test and the Kruskall-Wallis analysis of variance (25) were used to evaluate associations between preseason and postseason DRS and possible covariates.

Multivariate regression analysis (26) was used to evaluate the effect of baseline levels of spirometric indices on the change in DRS from preseason to postseason. Because FVC, FEV_1, and FEF_{25-75} are not strictly independent measures of pulmonary function, multivariate regression permits estimation of the joint effect of these measures with adjustment for the correlation between them.

It was observed that baseline DRS was related to only one covariate and not related to initial levels of forced expiratory volumes. Therefore, the analysis proposed by Vollmer (27) was undertaken to determine to what extent the crude differences between preseason and postseason DRS were due to regression to the mean (RTM) effects. Only two observation times were available; therefore, DRS were computed from each replicate (3) prefire and postfire season FEV_1. The regression of these three DRS pairs on time for each subject provided the estimate of within-subject variance required by the method. Because the analysis indicated that the crude pre-fire and post-fire season differences (based either on the mean or first postdose FEV_1) were unlikely to be biased by RTM, crude differences were used in the analyses.

Differences between preseason and postseason spirometric indices and DRS were assessed with the paired *t* test. All statistical analyses were carried out with the use of SAS for personal computers (28).

Exposure Assessment

An attempt was made to monitor exposure to some components of smoke (aldehydes, carbon monoxide, and particulate) at an active fire. However, by the time the team arrived at the site of the fire chosen for study, most of the blaze had been extinguished, and there was relatively little smoke. Some data were obtained that showed the presence of formaldehyde and respirable particulate. These data are presented in another report (20).

Because Hotshot crews remain together for the entire fire season, "Hotshot crew" was used as a marker to evaluate the effect of differences in exposure on changes in forced expiratory volumes and DRS.

Results

Demographic and Occupational Characteristics

Of the 63 fire fighters, 55 (87%) were male and 8 (13%) were female (table 1). Upon initial evaluation of the data, female crew members were not found to be different from the male crew members with respect to age, Hotshot crew membership, history of respiratory disease, or smoking history.

Wildland fire fighters are employed as full-time employees or as seasonal employees. Full-time employees fight fires during the fire season, as well as perform administrative duties throughout the entire year. Seasonal workers are hired for the fire season only. Firefighters were exposed to little smoke during the off-season. There was a significant difference in fire seasons worked between full-time

TABLE 1

CHARACTERISTICS OF SIXTY-THREE WILDLAND FIRE FIGHTERS FROM NORTHERN CALIFORNIA AND MONTANA, 1989

Characteristics	Median (yr) (n)	(%)	Range
Age, yr	27		19–48
Male, n = 55	28.6		19–48
Female, n = 8	26		20–38
Years as a firefighter, n = 60*	4		1–28
Fulltime employee, n = 16	11.5		3–28
Seasonal employee, n = 44	3		1–15
Pulmonary history			
Smoking			
Current	5	8	
Former	12	19	
Never	46	73	
Asthma	6	10	
Allergies	25	39	
Symptoms			
None	29	46	
Upper†	30	48	
Lower‡	4	6	

* 1989 was the first fire season for three fire fighters.

† Irritated or runny eyes, irritated nose or sore throat.

‡ Cough, phlegm, wheeze, shortness of breath, or chest tightness.

(median = 11.5 years) and seasonal employees (median, 3.0 yr) ($p < 0.0001$).

The 21 fire fighters not available for postseason testing were not substantially different from those who participated in postseason testing in terms of age, smoking history, asthma and/or allergy history, and full-time versus seasonal employment. These 21 subjects were more likely to be female (30 versus 15%), had a greater mean number of years of firefighting experience (7.6 versus 4), and were more likely to have lower respiratory symptoms (23 versus 4%). The reason for the increased percentage of female fire fighters among, and the greater firefighting experience of, these subjects is that eight fire fighters from an elite, leadership-training, Hotshot crew (to which women were actively recruited) could not participate in postseason testing because of a scheduling problem.

Of the final study population, 73% of the subjects (46 of 63) were never smokers, 19% (12 of 63) were former smokers, and 8% (five of 63) were current smokers at the time of the study. Smokers were evenly distributed among Hotshot crews. One current smoker gave a prior history of asthma; two gave a history of allergies. There were six subjects who gave a history of asthma in the past; of these, only one gave a history of recent lower respiratory tract symptoms (wheeze and cough).

Spirometry

Preseason and postseason percent predicted values for FVC and FEV_1 were normal for both female and male subjects (table 2). However, there were significant mean individual declines of 0.09, 0.15, and 0.44 L/s in postseason values of FVC, FEV_1, and FEF_{25-75}, respectively (table 2). There were no consistent significant relationships between mean individual declines of FVC or FEV_1 and any of the covariates investigated (smoking status, history of asthma or allergies, full-time or seasonal employment status, history of upper/lower respiratory tract symptoms, Hotshot crew membership; data available on request).

Methacholine Challenge Testing

In the univariate analyses, there were no significant associations between the preseason or postseason level of DRS and history of smoking (Wilcoxon's rank sum test). Baseline pulmonary function, Hotshot crew membership, or history of upper/lower respiratory tract symptoms also did not show any associations with preseason or postseason DRS level (Kruskall-Wallis ANOVA). There was no correlation between years of employment as a fire fighter and the level of preseason or postseason DRS. There was a significant association between the level of preseason and postseason DRS and a history of allergies (Preseason DRS: with allergies, median = 0.43, n = 25; preseason DRS: without allergies, median = 0.21, n = 38, $p < 0.01$. Postseason DRS: with allergies, median = 0.28, n = 38, $p < 0.01$; Wilcoxon's rank sum test) and a suggestive association for a history of asthma (Preseason DRS: with history of asthma, median = 0.28, n = 57, p = 0.16. Postseason DRS: with history of asthma, median = 0.87, n = 6; postseason DRS: without history of asthma, median = 57, p = 0.08; Wilcoxon's rank sum test). However, if the only one of six subjects with a history of asthma who had concurrent lower respiratory tract symptoms was removed from the analysis, the apparent association between asthma and preseason and postseason DRS disappeared (p = 0.41 and p = 0.23, respectively).

When the population was evaluated as a whole, there was a statistically significant increase in the mean individual postseason DRS compared with the preseason DRS (p = 0.02) (table 3). This difference was not associated with the covariates: sex, history of smoking, history of allergies, full-time versus seasonal employment, or Hotshot crew. However, the four subjects with lower respiratory symptoms appeared to have a greater increase in level of DRS than did the remainder of the subjects (p = 0.06, ANOVA). Similarly, the six subjects with a history of asthma (five of whom were asymptomatic) appeared to have a greater increase in level of DRS than those without such a history, although this was not statistically significant (p = 0.24).

TABLE 2

COMPARISON OF PRESEASON AND POSTSEASON MEAN FORCED EXPIRATORY VOLUMES IN 63 WILDLAND FIRE FIGHTERS

	Preseason		Postseason		Individual Differences		95% Confidence Limits
	(L)	(% pred)	(L)	(% pred)	Mean	SD	
FVC, L	5.4	110	5.35	107	0.09	0.18	0.05, 0.13
FEV_1, L	4.53	108	4.25	104	0.15	0.18	0.13, 0.17
FEF_{25-75}, L/A	4.51	93	4.02	85	0.44	0.74	0.26, 0.62

TABLE 3

COMPARISON OF PRESEASON AND POSTSEASON DOSE-RESPONSE SLOPES (DRS)* IN 63 WILDLAND FIRE FIGHTERS

	Preseason Median	Postseason Median	Individual Differences† Mean	SD	95% Confidence Limits
Log, DRS + 1	0.28	0.32	0.15	0.54	0.02, 0.28‡

* Percent decline in FEV_1 at the termination of the test from baseline FEV_1 divided by the final cumulative dose of methacholine administered (micromoles-1).

† Mean of individual differences of log (DRS + 1).

‡ p = 0.02.

Discussion

Previous investigations of municipal fire fighters have demonstrated acute decrements in forced expiratory volumes (1–4) and increases in nonspecific airway responsiveness related to fire fighting (3, 4). The present investigation extends these observations to wildland fire fighters over a single 5-month fire season in 1989. Small, but statistically significant, decrements in FVC, FEV_1, and FEF_{25-75} were found at the end of the fire season in comparison with preseason levels. Postseason airway responsiveness to MCh, expressed as the DRS, also demonstrated a significant increase over baseline.

The study design does not allow us to attribute these changes in lung function specifically to smoke exposure. It is possible that there is some other aspect of wildland fire fighting that is responsible for the observed effects. The small number of subjects available limited the statistical power of the study to detect factors that may have influenced the changes in forced expiratory volumes and flows and DRS. Nonetheless, the data suggest that the presence of current lower respiratory symptoms and a history of asthma, but not baseline levels of forced expiratory volumes and flows, are associated with increases in nonspecific airway responsiveness caused by wildland fire fighting. Although not statistically significant, those subjects with a history of asthma had a consistently higher level of preseason and postseason DRS than did those that did not. These same subjects also had a greater magnitude of increase in DRS from preseason to postseason. A study of municipal fire fighters by Sherman and coworkers (4), similarly limited by small numbers, also failed to observe an effect of preexposure lung function (specific conductance) on the increase in airway responsiveness associated with exposure to a fire. Moreover, that study, in keeping with the present investigation, also did not observe an independent effect of cigarette smoking on the relationship.

The increase in airway responsiveness in the present study was most marked in the four fire fighters with a current or past history of lower respiratory symptoms. Thus, it is possible that a simple respiratory illness questionnaire such as we administered may be useful in the identification of fire fighters at greatest risk of adverse respiratory outcomes. Protective intervention (e.g., better training in the use of respiratory protective equipment or exclusion from exposure) could then be provided. Brandt-Rauf and coworkers (16) reported that those municipal fire fighters not wearing respiratory protective gear had greater decreases in FVC and FEV_1 (0.22 and 0.19 L, respectively) than did those that did wear protection (−0.09 and −0.02 L, respectively). Tepper and coworkers (12) also demonstrated a 1.7 times greater decline in FEV_1 in unprotected fire fighters. Further study of methods to protect wildland fire fighters is clearly indicated since municipal-style respiratory protective equipment is heavy, confining, and impractical to use during active wildland fire fighting. Lightweight, cooler respiratory protective gear needs to be developed for the special circumstances of wildland fire fighting.

The lack of exposure assessment is a limitation of the present study and of many other investigations (1–4, 6–15) of the effects of exposure to fires on respiratory health. It is particularly inconvenient for wildland fire fighters to wear air-monitoring pumps since they must often hike miles while carrying heavy fire fighting gear before reaching the site of the fire. Despite this inconvenience, exposure assessment is critical for determining which components of smoke are responsible for adverse health effects in wildland fire fighters. Brandt-Rauf and colleagues (29) noted that visual assessment of smoke intensity by fire fighters grossly underestimated the true level of toxic pyrolysis products present in that smoke. Sampling of a few essential components of smoke, e.g., aldehydes and respirable particulate with the use of lightweight air-monitoring equipment would be valuable in this regard.

The results of several studies of municipal fire fighters suggest that there may be a cumulative effect from repeated exposure to smoke leading to chronic pulmonary dysfunction (12, 13, 15). In particular, Tepper and coworkers (12) observed that active fire fighters in Baltimore experienced a decline in FEV_1 (adjusted for smoking) that was approximately 2.5 times greater than that of retired fire fighters. The experience of municipal fire fighters, however, cannot be generalized automatically to wildland fire fighters. Municipal fire fighters are exposed to smoke on a year-round basis. In contrast, wildland fire fighters, seasonal and full-time, are exposed for only a portion of the year, during the hot, dry summer months. Our questionnaire data indicated that none of the subjects in the present study worked as municipal fire fighters during the off-season, nor were they exposed to any other source of smoke. It is conceivable, then, that the acute functional changes observed over the fire season resolve during the 5 to 6 months of the off-season. This pattern of acute change followed by relatively long respite from exposure may protect against the chronic functional changes seen in municipal fire fighters. A longer study, covering several fire seasons would help to clarify this point. A longitudinal study would also help to define other health outcomes in this population by compiling a data base of exposure information, past medical history, smoking history, and work history. Information on the occupational health problems of wildland fire fighters is sorely lacking.

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